ATLANTIS PRESS
Advances in Intelligent Systems Research, volume 166
7th Scientific Conference on Information Technologies for Intelligent Decision Making Support (ITIDS 2019)

Information Support of Development of Consolidated Solutions in the Development of a System of Collection and Transportation MSW Based on GIS Technologies

Vladimir Gvozdev
Department of Engineering Cybernetics
Ufa State Aviation Technical University
Ufa, Russia
wega55@mail

Olga Khristodulo
Department of Geographical Information Systems
Ufa State Aviation Technical University
Ufa, Russia
o-hristodulo@mail.ru

Elvina Fakhretdinova
Department of Geographical Information Systems
Ufa State Aviation Technical University
Ufa, Russia
fbelvina1395@mail.ru

***Abstract*—This article compiles the features of different approaches to solid municipal waste management in industrialized countries, in the subjects of the Russian Federation and in the Republic of Bashkortostan. One of the components of the fundamental scientific problem, which is a necessary condition for effective and efficient management, is the development of consensual approaches to solving the problems of waste management by all stakeholders. Currently, much attention is paid to the development of theoretical, methodological, model bases of management of complex systems and the development of tools for solving management problems. This article focuses on GIS technology as a tool base for solving the problems of information support of the MSW management on the territory of the Republic of Bashkortostan.**

Keywords—municipal solid waste, GIS technologies, waste management system, landfills, recycling, logistics

I. INTRODUCTION

One of the most actual social problems in the world today is the problem connected with the formation, accumulation, burial, recycling and disposal of waste. Today, in Russia, in general, and in the Republic of Bashkortostan, in particular, there is a significant increase in waste formation, which is primarily connected with the high rates of social and economic development of the society [1, 2]. Annually about two million tons of municipal solid waste (MSW) are generated in the Republic of Bashkortostan, which includes, on average, about 250–300 kilogram of waste for each citizen of the republic [3].

The priority in the field of waste management is the transition from the burial of waste to its recycling. But despite this, over the years, the average level of use of waste as secondary raw materials is about 3% of the total annual volume. And 97% of the waste is placed in specialized landfills and dumps, where it is simply buried in the ground, thereby getting rid of raw materials suitable for recycling. Only economically rational and highly liquid waste, such as polymeric materials, waste and scrap of ferrous and non-ferrous metals, clean textile and wood waste are involved in economic circulation [3].

Therefore, while our country has not become a huge dump yet, it is necessary to look for the effective solutions in the field of waste management. In this case, the factor of difficulty in making consolidated decisions in the MSW management is the conflict of the purposes in various classes of subjects of management to which belong:

- employees of state structures, developing a set of legal norms and establishing rules for waste management;
- investors trying to get the maximum profit from the enterprise, building them mainly near settlements;
- scientists developing new and studying existing technologies of waste recycling;
- population and social movements that care about their health in the places of residence.

The legal and economic basis for the MSW management is various target-oriented programs, which top - priority goal is the MSW collection and transportation. So, in a number of regions, including the Republic of Bashkortostan, waste management strategies have been worked out, involving the achievement of target indicators for the level of recycling and the reduction of environmental impact, as well as the use of the best available technologies [3, 4].

The main problem in this case is the lack of development of the instrumental base of the multi-aspect analysis of the MSW management problem and also the structured presentation of information.

The desire for the integrated use of heterogeneous information, containing not only attributive, but also spatial characteristics, encourages experts to use the best methods and means of obtaining and analyzing this kind of data to assess the observed situation. Geographic information systems (GIS-technologies) can be used as such tools for structuring, visualizing and comparing heterogeneous, territorial-oriented data. These technologies significantly improve the planning of work in the field of waste management, because they provide an opportunity to analyze the geographical location of MSW landfills, their quantitative and qualitative characteristics, to consider alternative placement of waste collection and recycling centers in terms of transportation and storage costs, which, finally, will allow

to make informed decisions in the field of waste management.

As a methodology for studying complex systems of different nature, it is possible to use various methods of system analysis, creating the basis for analyzing the territorial and temporal variability of indicators of the state of components of territorial systems under conditions of uncertainty of properties of interconnected processes due to natural, social, technological factors, including the processes of emergence, storage, transportation and recycling of waste.

To solve the problems of information support of the MSW management on the territory of the Republic of Bashkortostan, it is necessary to adapt GIS technologies and system analysis methods taking into account the specifics of the MSW management, which will allow to answer what is happening in the waste management system reasonably, whether the situation improves or not, and evaluate how appropriate and reasonable the places for the construction of waste sorting and waste recycling enterprises are selected. One of the components of this problem is the improvement of approaches to the waste collection and transportation, which will not only optimize routes and, therefore, the costs of transportation of MSW, but also find the best places for construction of waste sorting and waste recycling enterprises.

II. Analysis of approaches to the municipal solid waste management in industrialized countries

The basis of the waste management system in the European Union is the Waste Management Concept, which includes the collection and transportation of waste on the basis of intelligent technologies, partially mechanized and automated sorting, as well as deep recycling.

For example, in European countries, the USA and Japan, the separate collection of wastes is widely practiced in places of its formation, which mostly prevents entering of valuable (unpolluted waste paper, glass, plastics, metals) and dangerous (used fluorescent lamps, accumulators, batteries) components into the MSW.

The realization of selective collection of MSW components as a raw material for recycling in European cities is based on the organization of explanatory and information work among the population (starting with school curricula) and the use of special containers installed in places of waste formation. Separate collection of waste is often stimulated by a reduction of the charge for the disposal of MSW (mainly the transportation of the unutilized part of MSW is paid) [5].

So, in the field of recycling and energy production from the waste, Sweden leads among European countries. No more than 1% of waste is sent to dumps, the rest as a result of recycling provides 20% of volumes of central heating. A similar situation is observed in Finland. Here 97% of waste is disposed [6]. Many municipalities in Sweden, realizing that waste is a profitable business, relied on waste-based thermal power plants, which finally led to the fact that Swedish waste was not enough, and there was a need for its import. Therefore, the significant amount of waste is imported from abroad into this Scandinavian country.

In the field of industrial recycling of MSW, the greatest success was achieved by Germany, whose government adopted the law prohibiting the export of organic waste to dumps, including MSW, without prior preparation since June 1, 2005. The level of waste recycling in Germany in 2010 reached 62%, almost nothing was sent to dumps, and the percentage of waste disposal at dumps is close to 0% [6].

In Switzerland at the moment there are no dumps. Some of the waste is recycled, and some is disposed in waste burning plants. By the way, there are 30 of them [6].

In Poland, 26% of municipal waste is reused as raw material, another 16% is composted for obtaining energy and fertilizer, and 13% is burned. As a result, 44% of the generated waste is buried [6].

In the USA, the transportation and further recycling of various types of waste is not only a solution to environmental issues, but it is also considered quite a profitable business. In America, special programs have been developed which work to stimulate waste recycling: 98% of all produced glass is recycled, plastic packages of food and beverages are selected directly in the waste recycling plants, and only 15% of MSW is disposed by waste burning plants. At the same time, environmental law in the United States plays an increasingly important role in stimulating the production of secondary raw materials from waste. Burial and burning of waste, taking into account the compliance of all environmental standards, is three times more expensive than recycling [7].

Japan has also made significant progress in recycling, where the energy potential of municipal solid waste is widely used: 65% of its amount is burnt [8].

Based on these examples, it can be noted that most industrialized countries use thermal methods of waste disposal, while in our country there are many opponents of this technology, because of the «extremely high» emission of dioxins from these enterprises. But, however, modern waste burning plants are fully automated, require a minimal staff, and are also characterized by complete burning of waste without the formation of harmful emissions in the atmosphere. That is possible due to the fact that a very high temperature (up to 1200 C) is created in cremators, and special additives to waste do not allow the formation of harmful emissions, besides the smoke fumes go through a whole cleaning system for its full impurity absorption.

At first sight, it may seem that burning is not a solution to the global problem of increasing waste. But the use of the latest purification technologies and tracking the level of emissions of the plant, allow to burn waste without harm to the health of the population and the environment. As proof of that, in the city of Vienna, which is one of the cleanest capitals in Europe, the waste recycling plant is located in the centre of the capital of Austria [9].

Moreover, it should also be taken into consideration that emissions from the spontaneous combustion of landfills significantly exceed the effects of waste burning plants, which, with the help of modern gas cleaning systems, vent relatively less harmful substances into the air. Whereas more greenhouse gases, nitrogen oxides, dioxins, hydrocarbons and non-methane organic compounds are vented in the landfills.

Thus, the experience of foreign countries shows that, due to the waste recycling, it is possible not only to protect the

environment and the population from negative impacts, but also to make a profit, which can be made by competent waste recycling, as a result of which it is possible to obtain not only secondary resources, but also additional energy.

III. Analysis of approaches of the municipal solid waste management in the subjects of the Russian Federation

The transition from landfill disposal to industrial recycling is the main trend in solving the problem of waste management in the world practice. And the system development of the MSW collection and transportation should be considered as the first step in solving this problem.

One of such solutions should be considered the transition of all subjects of the Russian Federation, and the Republic of Bashkortostan, in particular, to the territorial scheme of waste management, according to which the territory of the republic was divided into five territorial zones, where regional operators are responsible for collection, transportation, recycling, disposal and the burial of municipal solid waste [4]. Among other things, this scheme assumes the increase of tariffs on waste collection for the population, due to the fact that caring for the environment requires new investments, which means that it is necessary to build new recycling plants as well as waste sorting and waste transferring stations. All this requires financial investments, which should be compensated by increasing the tariff on waste collection.

However, in our opinion, this solution will not contribute the economic stimulation of the waste recycling industry, because the cost of disposal at landfills will still remain low. In other words, the creation and maintenance of landfills is much cheaper than financing a new plant. This is connected with the fact that there is a lot of land in the country; therefore, it is much easier and cheaper to take waste to the dump than to build expensive plants for their recycling or burning.

From our point of view, the increase in tariffs will not help to deal with accumulated waste, to eliminate large deposits of waste, which, in the literal sense of the word, poison people's lives. The application of this approach, despite the fact that it is effective, due to the emergence of new investments, but it is not sufficient and ineffective. Therefore, to eliminate the waste disaster, it is necessary to look for more efficient and effective methods of waste control.

In various regions of Russia attempts to build industrial enterprises of burning household and other waste are being made. So, today the country plans to build five waste burning plants (WBP): 4 plants in the Moscow region and one in the Republic of Tatarstan. At the same time, it is planned that four burning plants of the Moscow region will be able to recycle about 2.8 million tons of waste per year totally, which will reduce the percentage of waste which is sent to landfills for 25% [10].

These plants will be built with the help of technology of the Swiss-Japanese company Hitachi Zosen Inova. The waste will become a kind of fuel for the power station and along with MSW recycling the enterprise will generate electricity. Moscow plants are designed to burn 700 thousand tons per year and produce 70 megawatts of electricity. Kazan plant will be able to receive up to 550 thousand tons of waste and to produce 55 megawatts of electricity.

Also relatively recently - in May 2018, the largest waste sorting complex in Russia, with a capacity of 470 thousand tons per year, 60 tons per hour, was opened near Dzerzhinsk in the Nizhny Novgorod region. He recycles 10% of the received MSW, and the rest buries at the landfill. The automated mechanism sorts 30% of the incoming waste into 13 fractions, and then launches it under a press and packs it into briquettes. In the future, each briquette goes on sale [11].

But among the waste recycling complexes of Russia one of the most technically advanced is the Engels waste recycling complex, where in 2016 over than 100 tons of waste paper (30 - 35% of the total waste) were removed from the total MSW and sent for recycling. As a result of work of this complex more than 20 fractions of reused resources are produced, which are subsequently sent to 6 regions of Russia for recycling and production of the final product [12].

The first step from the point of view of improving the efficiency of waste management can be the optimization of their transportation, that is, the introduction of logistic methods into waste management. By optimization of traffic flows it is possible to achieve a significant reduction in the share of transport costs and, consequently, to reduce tariffs on waste disposal for consumers.

In this case, the main tasks of waste logistics are minimization of the cost of waste transportation from their collection places to disposal sites, in particular, due to the optimization of transport routes [13]. To do this, it is necessary to use a complex combination of different types of transport. So, the collection of waste from container sites, as a rule, is made by road transport, which delivers them directly to the recycling sites or to transfer stations, where they are compacted and reloaded onto heavy vehicles. But besides this, the transportation of waste by rail is also known in the world practice. Such regulation of road and rail transportation will reduce the cost of transportation, as well as provide the possibility of centralized recycling at large specialized enterprises. In particular, in the Republic of Bashkortostan, according to the Program, when MSW is situated over a distance of more than 55 km, it is considered economically reasonable to use railway platforms as vehicles [3, 14] (fig. 1).

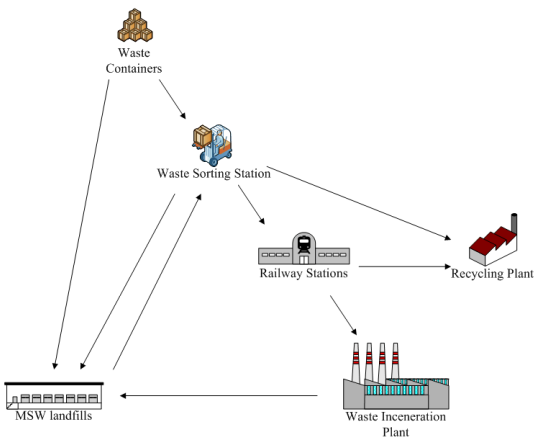

Fig. 1. Possible scheme of waste transportation

GIS technologies are designed to solve practical problems that require the analysis and evaluation of complex information about the infrastructure of a territory in combination with spatial cartographic data. Therefore, GIS technologies can serve as the instrumental basis for the solution of optimization of traffic flows, which will significantly help to improve the efficiency of the transportation system of MSW. Such technologies provide for the accumulation of geographically coordinated (coordinate-attached) data, its system analysis, and interpretation in the form of cartographic images by means of computer graphics.

Therefore, it is necessary to adapt GIS technologies as an instrumental basis for taking into account the territorial aspect in the system of collection and transportation of MSW.

IV. Aspect analysis of the system of collection and transportation of municipal solid waste in the Republic of Bashkortostan

As the practice shows, for the effective functioning of the waste management system, it is necessary to operate with very large volumes of heterogeneous information, some of which are tied to a specific point in the geographical space and constantly changing. Therefore, it is necessary to create an information database where maps of different scales should be entered; databases on human settlements; landfills; waste transferring and waste sorting stations; road network; volume of newly generated waste, etc. And not only desktop applications, but also various mobile applications can serve as an instrumental basis for making and using the information base. The architecture of such GIS system for the collection and transportation of MSW is presented in Fig. 2.

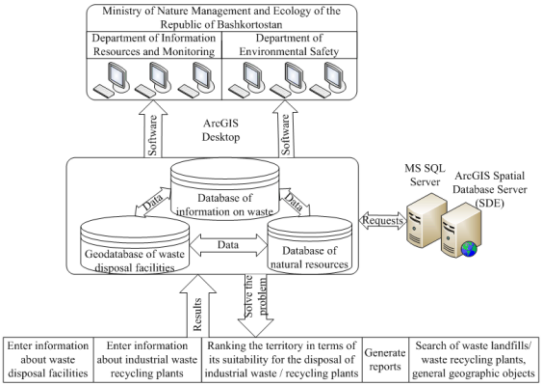

Fig. 2. Architecture GIS system for the collection and transportation of MSW

According to the Ministry of Nature Management and Ecology of the Republic of Bashkortostan as of 2017 there are 49 MSW polygons, 14 of which are filled more than 75% [4, 15, 16]. In addition to MSW landfills there are about 2500 unauthorized landfills, covering the area of more than two thousand hectares of land in the region.

In total in the territory of the Republic of Bashkortostan there are 245 railway stations, platforms and flag stations, only 38 railway stations of which can receive / issue and dispatch cargo (for transportation of waste) (fig. 3).

In addition, the existing waste management scheme on the territory of the Republic of Bashkortostan involves receiving waste from settlements, from the territories of the water protection zones and recreation areas located at a distance of no more than 35 km from the location of the landfill (fig. 4) [3].

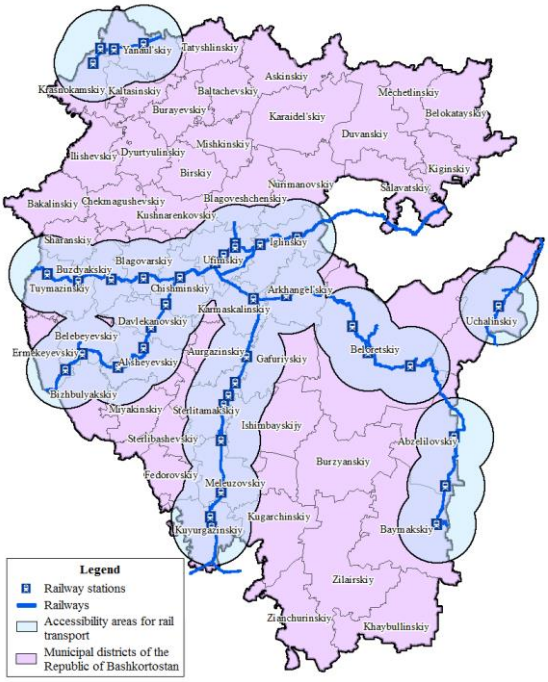

Fig. 3. Map of availability zones for waste transportation by rail in the Republic of Bashkortostan

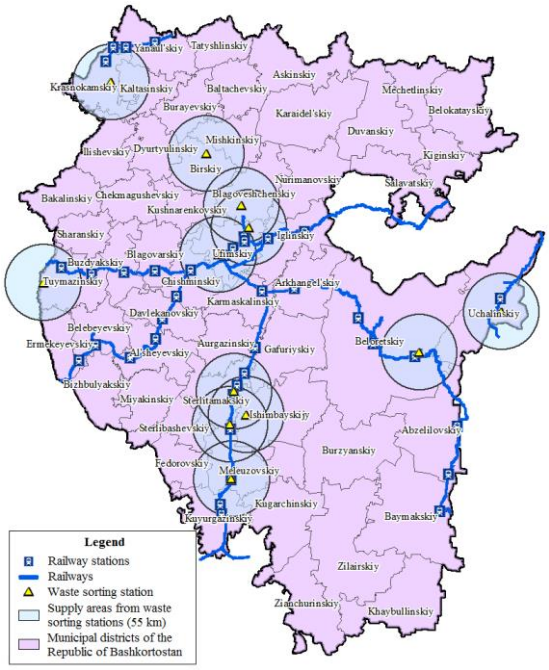

Fig. 4. Map of zones of direct supplies to landfills of the Republic of Bashkortostan

When exporting waste from settlements located at a distance of more than 35 km from the landfill, it is necessary

to build waste transfer and waste sorting stations. At the same time, the distance should not exceed 55 km [3]. Thanks to these enterprises, the compaction of MSW solves the problem of optimal loading of transport during the transportation of waste for long distances, reduces the number of garbage trucks and reduces the cost of removing MSW. Now on the territory of the Republic of Bashkortostan there are 13 waste sorting complexes of various capacities (fig. 5) in the cities of Ufa (3 pcs.), Sterlitamak, Salavat, Neftekamsk, Oktyabrsky, Beloretsk, Ishimbay, Meleuz, Blagoveshchensk, Birsk and in Uchaly district [4, 15].

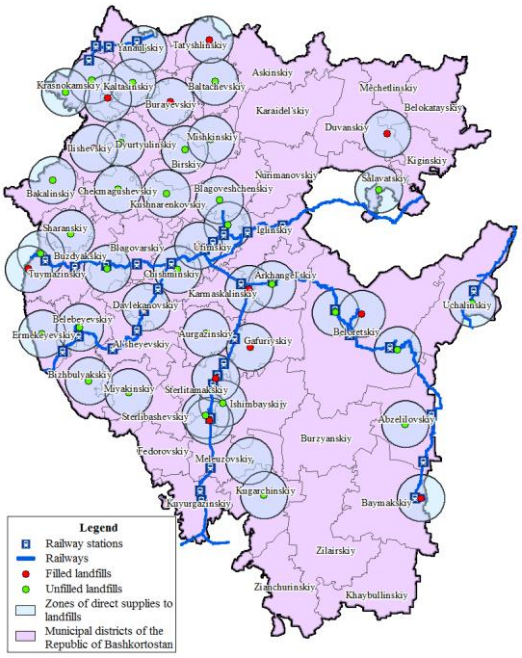

Fig. 5. Map of supply zones from waste sorting stations of the Republic of Bashkortostan

To judge how effectively the existing scheme of waste management works, on the basis of Figures 3-5, we calculated some indicators presented in the Table 1, where you can see that almost all waste sorting stations are situated in the zone of rail transportation, what cannot be said about the MSW landfills (less than 50%).

TABLE I.

Indicator	Value
Proportion of waste sorting stations in the accessibility zone at railway stations	0,92
Proportion of landfills in the area of accessibility of waste sorting stations	0,37
Proportion of landfills in the area of accessibility at the railway station	0,47
Waste volumes from waste sorting stations (capacity) in the accessibility zone by rail, thousand tons / year	1237,8

After waste sorting stations, briquettes of sorted waste must be sent to waste recycling enterprises, and those wastes that could not be avoided and which cannot be recycled are sent for recycling to waste burning plants.

V. Conclusion

One of the components of a complex analysis of alternative solutions of the problem connected with the collection and transportation of MSW are tools implemented on the basis of GIS technologies. By means of GIS it is possible not only to visualize spatial data on the objects of collection and disposal of MSW, but also to make a joint analysis of the transport network and the sites for the collection, sorting and disposal of waste.

The use of GIS technologies creates conditions for reducing the cost of waste collection and its transportation, by optimizing routes from waste collection sites to recycling sites at specialized enterprises, as well as increasing the reasonableness of choosing sites for building new waste sorting enterprises taking into account the interests of government agencies, businesses, public organizations and the population.

Acknowledgment

The results of the research presented in this article were partially supported by a grant 18-08-00885 - A «Methodological foundations of multi-criteria management of the process of choosing the location of industrial waste recycling enterprises based on the principles of evergetics».

References

[1] Khristodulo O.I. Development of an information system for placing objects of technological hazards using fuzzy logic / O.I. Christodoulo, I.F. Salimzyanov, N.R. Gareeva // Scientific journal "Scientific and technical statements SPbGPU. Computer science. Telecommunications. Control". - St. Petersburg, Russia, 2015, V. 5 (229), pp. 47 - 58. (in Russian).

[2] Khristodulo O., Davletbakova Z., Gvozdev V. Spatial Information Processing for Decision-making Support of Siting Sources of Technogenic Hazards Using Computer Technologies // 2nd International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM). - Chelyabinsk, 2017, pp. 1-5.

[3] The republican target program “Improvement of the system of management of municipal solid waste in the Republic of Bashkortostan for 2011–2020”, approved by the Decree of the Government of the Republic of Bashkortostan of 18.11.2011 no. 412. - Ufa, 2011, 33 p. (in Russian).

[4] The territorial scheme of waste management, including solid municipal waste in the Republic of Bashkortostan, approved by the Government of the Republic of Bashkortostan of 03.11.2016 no. 480. - Ufa, 2016, 302 p. (in Russian).

[5] Waste management system in EU countries. (in Russian). Available at: http://waste-nn.ru/sistema-upravleniya-othodami-v-stranah-es (accessed 26 February 2019).

[6] Statistical Service of the European Union (Eurostat). Available at: https://ec.europa.eu/eurostat (accessed 22 February 2019).

[7] Experience of developed countries in waste management. (in Russian). Available at: https://www.waste.ru/modules/section/item.php?itemid=328 (accessed 16 February 2019).

[8] The problem of municipal solid waste in Japan. Modern solutions. (in Russian). Available at: https://www.waste.ru/modules/section/item.php?itemid=207 (accessed 10 February 2019).

[9] An incinerator in Vienna. Recycling garbage without harm to the environment. (in Russian). Available at: http://www.musorunet.ru/musorosjigatelnyi_zavod_v_vene.php (accessed 16 February 2019).

[10] Russia will build five modern waste incineration complexes. (in Russian). Available at: https://rg.ru/2017/04/03/v-rossii-postroiat-piat-sovremennyh-musoroszhigatelnyh-kompleksov.html (accessed 26 February 2019).

[11] Russia's largest waste sorting complex has earned in the Nizhny Novgorod region. (in Russian). Available at: https://nn.mk.ru/social/2018/05/30/krupneyshiy-v-rossii-

musorosortirovochnyy-kompleks-zarabotal-v-nizhegorodskoy-oblasti.html (accessed 26 February 2019).

[12] The waste recycling complex in Engels will be able to solve the problem of unauthorized landfills in the region. (in Russian). Available at: http://privolgskiy.ru/musoropererabatyvayushhij-kompleks-v-engelse-smozhet-reshit-problemu-nesankcionirovannyx-svalok-na-territorii-oblasti/ (accessed 3 March 2019).

[13] Valery Gokhman GIS in solving transport problems // ArcReview. 2016, V. 1 (76). (in Russian).

[14] The concept of solid waste management / Research Center for Resource Saving and Waste Management. - Moscow, 2000. 72 p. (in Russian).

[15] State report on the state of natural resources and the environment of the Republic of Bashkortostan in 2017 / Ministry of Nature Management and Ecology of the Republic of Bashkortostan. - Ufa, 2017, 330 p. (in Russian).

[16] State report on the state of natural resources and the environment of the Republic of Bashkortostan in 2017 / Ministry of Nature Management and Ecology of the Republic of Bashkortostan. - Ufa, 2016, 316 p. (in Russian).

[17] Lilliana Abarca Guerrero, Ger Maas, William Hogland Solid waste management challenges for cities in developing countries //Waste Management. – 2013, V.33, pp. 220-232.

[18] On waste production and consumption: Feder. The law grew. Federations of June 24, 1998 no. 89-fz / Official Internet portal of legal information. Available at: http://pravo.gov.ru. (accessed 26 February 2019). (in Russian).

[19] Federal Law no. 458 dated December 29, 2014 (as amended on April 3, 2017) «On Amendments to the Federal Law On Production and Consumption Wastes», Certain Legislative Acts of the Russian Federation and Declaring Certain Legislative Acts) of the Russian Federation. (in Russian).

[20] Sim N.M., Wilson D.C., Smith S.R., Velis C.A. Waste management and recycling in the former soviet union: the city of Bishkek, Kyrgyz Republic (Kyrgyzstan) // Waste Management & Research, 2013. V. 10 (31). pp. 106-125.

[21] On the environmental situation on the territory of the Republic of Bashkortostan in 2014: state. report / Ministry of Nature Management and Ecology of the Republic of Bashkortostan. - Ufa, 2015, 172 p. (in Russian).

[22] On the implementation of regional state environmental supervision in the territory of the Republic of Bashkortostan in 2014: state. report / Ministry of Nature Management and Ecology of the Republic of Bashkortostan. - Ufa, 2015, 150 p. (in Russian).

[23] Marshall R.E., Farahbakhsh K. Systems approaches to integrated solid waste management in developing countries // Waste management. – 2013, V. 4 (33), pp. 988-1003.

[24] Shen Y., Wang J., Chen X., Ge X., Chen M., Zhao R. Waste-to-energy: dehalogenation of plastic-containing wastes // Waste Management, 2016. V. 49, pp. 287-303.

[25] Masood M., Barlow C.Y., Wilson D.C. An assessment of the current municipal solid waste management system in Lahore, Pakistan // Waste Management & Research, 2014, V. 9 (32), pp. 834-847.